Distribution and habitat assessment of the Broad-headed Snake *Hoplocephalus bungaroides*

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ABSTRACT

Conservation reserves are commonly relied on as a primary means of conserving threatened species. We conducted surveys for the endangered Broad-headed Snake *Hoplocephalus bungaroides* across 236 sites in 10 conservation reserves of the Sydney region, to assess the present day distribution of this species. Surveys were targeted at rock outcrops, which provide critical shelter sites during the year. Sites were stratified on the basis of proximity to walking tracks and roads as a surrogate for potential anthropogenic disturbance. Despite the apparent suitability of much of the habitat surveyed, few Broad-headed Snakes were detected and in only four of the reserves. This confirms the rarity of this species and suggests that apparent habitat suitability within conservation reserves is an inadequate basis on which to conclude that a species may be reasonably conserved. Habitat disturbance was common across the reserves, often irrespective of distance from tracks and roads. Much of this disturbance appeared to be due to activities associated with hikers and reptile poachers, rather than rock thieves as previously postulated. The abundance of loose rocks (total rocks, snake preferred rocks) varied across reserves but was not related to distance to tracks and roads, or greater at sites where snakes were detected. We conclude that the conservation needs of this species are more urgent than previously reported.

Key words: *Hoplocephalus bungaroides,* reptile conservation, habitat disturbance, reptile poachers, protected area management, *Oedura lesueurii.*

Introduction

Conservation reserves form a fundamental element of strategies designed to conserve threatened species (e.g. Cogger *et al.* 1993; Goldingay *et al.* 1997; Haight *et al.* 2002; WallisDeVries 2004). Indeed, a system of reserves was considered critical to conserving threatened species in Australian forests (Commonwealth of Australia 1997). It is often assumed that the conservation requirements of threatened species are adequately satisfied if reserves containing suitable habitat occur within their geographic ranges. This notion requires verification via detailed survey in areas of predicted habitat.

The Broad-headed Snake *Hoplocephalus bungaroides* has one of the smallest geographic distributions for an Australian elapid (Longmore 1989; Cogger *et al.* 1993), being largely restricted to the sandstone formations of the Sydney basin (Cogger 2000; Swan *et al.* 2004). It has lost as much as 20% of its range as urbanisation has proceeded within the Sydney basin. Consequently, this species has undergone a drastic decline in abundance since European invasion (Hersey 1980; Shine and Fitzgerald 1989) and it has long been recognised as at risk of extinction (Krefft 1869; Hersey 1980). The Broad-headed Snake has been listed as endangered in New South Wales (NSW) since the inception of the *National Parks and Wildlife Act* 1974 and is currently recognised as endangered by the *Threatened Species Conservation Act 1995*. It is listed as vulnerable by the Commonwealth's *Environmental Protection and Biodiversity Conservation Act 1999*, though it was listed as endangered by the Commonwealth until 1997.

Unlike most threatened reptiles in NSW, the ecology of the Broad-headed Snake has been well documented (see Newell and Goldingay 2004). It is a habitat specialist, often relying on tree hollows during summer and exfoliated rock in rock outcrops during the cooler months (Webb and Shine 1997a, 1998a). These factors may make it particularly vulnerable to anthropogenic disturbance. Depletion of rock habitat via the collection of bush rock for garden ornamentation in areas around Sydney has been extensive (Shine *et al.* 1998). This has led to the listing of bush rock removal as a threatening process under the NSW *Threatened Species Conservation Act 1995*. Other forms of habitat degradation have been documented and appear to be extensive (Goldingay 1998; Goldingay and Newell 2000; Pringle *et al.* 2003).

Despite the fact that the Broad-headed Snake has been the subject of a number of studies during the last decade, the distribution of this species has received only limited attention. Shine *et al.* (1998) detected this species at 7 of 18 sites surveyed throughout the distribution inferred from museum specimens. More detailed information is needed to devise an appropriate conservation strategy for this species (Cogger *et al.* 1993). The present study had three aims: i) to conduct detailed surveys for the Broad-headed Snake through reserves to the north and west of Sydney where its distribution is poorly documented, ii) to assess the quality of the available loose rock habitat in those reserves, and iii) to assess the extent and cause of rock habitat disturbance in those reserves.

Methods

Study area

This study was conducted over a large area of National Park (NP) estate in the Sydney basin. The following reserves were surveyed: Ku-ring-gai Chase NP, Marramarra NP, Muogamarra Nature Reserve (NR), Dharug NP, Popran NP, Brisbane Water NP, Yengo NP, Blue Mountains NP and Wollemi NP (Fig. 1). All reserves contained potentially suitable habitat for the Broad-headed Snake and some had not been surveyed previously for this species. This species was known from Blue Mountains and Wollemi NPs (Cogger *et al.* 1993; Shine *et al.* 1998), Yengo NP (Shine *et al.* 1998), Dharug NP (NPWS 1998), Marramarra NP (NPWS 1999) and Ku-ring-gai Chase NP (NPWS 1999). Muogamarra NR is continuous with Marramarra NP so there was an expectation that it should occur there. The species is known historically from Ku-ring-gai Chase (NPWS 1999) and was recorded "on the shores of Middle Harbour" (Krefft 1869), located approximately 15 km south-west. Therefore, it seems reasonable to conclude that the species could still occur in this reserve. Popran NP adjoins Dharug NP while the Pacific Hwy separates Popran NP and Brisbane Water NP. Thus, it is possible the species occurs across all three reserves.

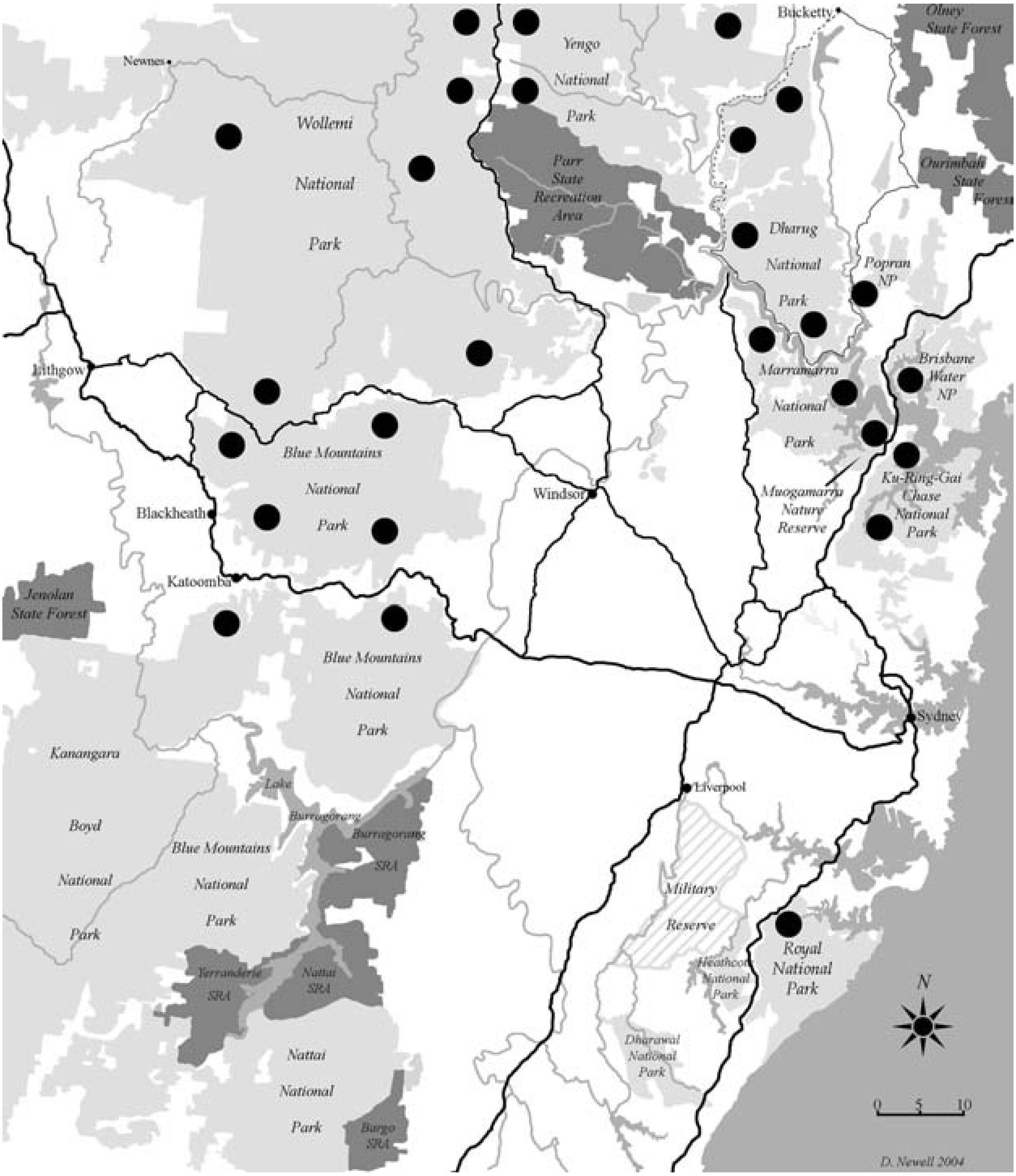

Figure 1. Surveys were conducted in ten reserves within the Sydney Basin. ● Indicates broad survey areas in each reserve.

Surveys were also conducted in Royal NP on the southern outskirts of Sydney where the distribution of the Broad-headed Snake had been established in an earlier study (Goldingay 1998). This reserve served as a reference for the level of survey effort required to detect the Broad-headed Snake. Surveys were conducted during the cooler months of the year (June - September) between 1998 and 2001.

Survey methods

Areas that potentially contained suitable habitat for the Broad-headed Snake were identified from topographic map sheets (1:25000). An area was deemed to be suitable if there was outcropping sandstone (ridges, rock ledges and cliff lines) that had a north through to west aspect. Broad-headed Snakes favour this aspect because it receives afternoon sun in the cooler months of the year (Webb and Shine 1998a; Pringle *et al.* 2003). A transect of approximately 200 x 30 m was surveyed at each site.

We selected sites near (<200 m) and far (>350 m) from roads and walking tracks to provide insight into whether distance has an influence on the incidence of anthropogenic disturbance. A stratification of survey sites by distance has been used previously (see Goldingay 1998; Goldingay and Newell 2000). Sites were separated by at least 200 m. Because of the extensive system of walking tracks and service trails, and their common location along rocky ridgelines, it was difficult to find sites that could be classified as 'far' in many of the reserves. Thus, the far category often contained fewer sites than the near category.

Surveys consisted of one or two people traversing a transect and carefully lifting all rocks positioned on a rock substrate that could reasonably be lifted by hand. When two people were present, each searched a separate area of the transect. All rocks lifted were placed back in their original position and great care was taken to avoid disturbance to the site. The time taken to search the transect was recorded for each person.

The quality of the rock habitat along each transect was assessed by counting the total number of rocks lifted and the number that were potentially suitable for use by the Broad-headed Snake. Rocks were considered suitable if they were positioned on a rock substrate, had less than 50% debris under them, were of an appropriate size class (>3 cm thick and at least 10 cm in length and width) and positioned relatively flat on the substrate. These are referred to as snake rocks. This follows the definition used by Goldingay (1998) and is consistent with the findings of Webb and Shine (1998a). While only rocks positioned on a rock substrate were targeted, the suitability of each rock could not be ascertained until it was lifted. All reptiles encountered under rocks were recorded.

Many rock outcrops were heavily dissected by crevices. These were also searched using a torch. The number of crevices searched and their suitability for Broad-headed Snakes was not quantified. Opportunistic searches of suitable rocks and crevices were also conducted in between transects, with many hundreds of rocks lifted this way. This was done in order to increase the chances of finding Broad-headed Snakes. However, snakes were only found under loose rocks on the transects.

Most transects were surveyed only once due to the large geographic area involved. However, a subset of sites was visited on two occasions over the four years of data collection to further increase survey effort for areas where the Broad-headed Snake is largely unknown. This made no difference to the detection of the Broad-headed Snake. Sites in Royal NP were surveyed annually and provide an index of the effectiveness of our methods.

In each reserve, we recorded information on the types of disturbance to the loose rock habitat that were observed. This included the use of rocks of a size used by Broad-headed Snakes to construct fireplaces and rock cairns. We noted when loose rocks had been removed, because a stencil remained on the rock platform (see also Shine *et al.* 1998).

Data analysis

Data for the total number of rocks lifted, the number of snake rocks and the number of Velvet Geckos *Oedura lesueurii* were analysed using a two-factor ANOVA with reserve and category as the factors. This lizard is a primary prey item of the Broad-headed Snake (Webb and Shine 1998b). Data were transformed by log (x+1) to improve normality for analysis. There was no significant interaction (P>0.3) between the two factors in any of the analyses.

Results

Suitability of habitat

We conducted surveys at 236 sites across the 10 reserves. Twenty-eight sites located between 200 and 350 m of tracks and roads were included to increase the survey coverage of the reserves but were omitted from the data analyses dealing with distance effects. There were 81 sites classified as 'far'. A total of 15601 rocks were lifted across all sites (this includes repeat visits) with a mean of 15% of total rocks considered to be suitable for use by Broad-headed Snakes (Table 1). The availability of loose rocks at sites varied from a mean of 27 to 79 per transect (Figure 2). A two-factor ANOVA revealed a significant difference among reserves ($F_{9,188}$ = 5.59, P = <0.001) in the total number of rocks searched, but not between site categories ($F_{1,188}$ = 0.009, P = 0.925).

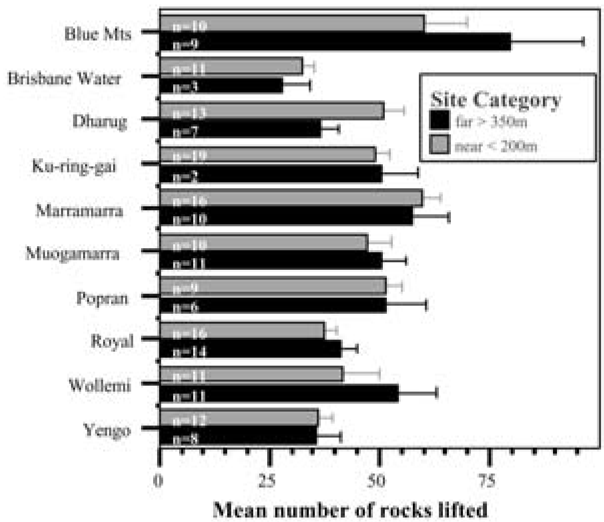

Figure 2. The mean number (± S.E) of total rocks lifted at transects near (<200m) and far (>350m) from roads or walking tracks in 10 reserves. Number on bars shows the sample size.

Table 1. Data recorded from surveys of 10 reserves in the Sydney basin. Repeats are the number of transects surveyed more than once. Where transects were surveyed on more than one occasion, we used the maximum count of each species in our totals. Rock values are the number lifted. Snake rocks (SR) are those of suitable dimensions and on a rock substrate (% = % of total for that reserve). - = absent.

National Park or Nature Reserve	Marramarra	Muogamarra	Ku-ring-gai	Dharug	Popran	Brisbane Water	Yengo	Wollemi	Blue Mountains	Royal
Total transects (repeats)	36(5)	23(3)	21(0)	23(4)	15(0)	16(0)	23(1)	24(0)	22(0)	33(21)
Total Rock	2043	1140	1038	1122	773	512	810	1109	1560	1332
Snake rocks (%)	354(17)	194(17)	156(15)	135(12)	117(15)	141(28)	81(10)	117(11)	73(5)	297(22)
Snakes										
Hoplocephalus bungaroides	-	-	-	-	-	-	1	1	2	6
Demansia psammophis	1	1	4	-	-	2	1	1	-	11
Pseudechis porphyriacus	-	1	1	-	-	-	-	-	-	-
Rhinoplocephalus nigrescens	1	-	-	1	-	1	1		7	15
Ramphotyphlops proximus	-	-	-	1	-	-	1	1	1	-
Furina diadema	-	-	-	-	-	-	-	-	-	1
Dendrelaphis punctulata	-	-	1	-	-	-	-	-	-	3
Morelia spilota	-	-	-	-	-	-	1	-	-	-
Boiga irregularis	1	-	-	-	-	-	-	-	-	-
Geckos										
Oedura lesueurii (per 100 SR)	24(7)	26(13)	20(13)	15(11)	21(18)	83(59)	26(32)	73(62)	49(67)	149(51)
Underwoodisaurus milii	5	2	-	6	-	-	2	-	-	1
Diplodactylus vittatus	1	1	-	1	-	-	3	2	-	2
Skinks										
Ctenotus taeniolatus	91	59	24	58	30	7	18	4	23	64
Bassiana platynota	9	8	2	4	7	5	-	3	2	13
Cryptoblepharus virgatus	10	3	2	1	7	3	2	-	2	14
Lampropholis delicata	1	6	3	-	1	-	-	-	9	17
Egernia whitii	9	3	2	1	4	2	2	1	-	5
Egernia cunninghami	5	4	1	-	1	-	-	2	-	1
Elamprus quoyii	-	-	-	-	-	-	-	-	10	-
Dragon										
Rankinia diemensis	-	-	-	-	-	-	3	2	-	-

The number of rocks suitable for Broad-headed Snakes (snake rocks) varied between 0 and 26 across all sites. The mean number of suitable rocks varied across reserves and site category (Figure 3). A two factor ANOVA revealed that the number of snake rocks per site differed significantly among reserves ($F_{9, 188} = 10.66$, $P = <0.001$) but did not differ between site categories ($F_{1, 188} = 0.489$, $P = 0.485$).

Detection of the Broad-headed Snake

The Broad-headed Snake was detected in four of the reserves surveyed (Table 1). Two individuals were located in the Blue Mountains NP (one near site, one far site). A single snake was detected in both Wollemi (far) and Yengo (near) NPs. Six Broad-headed Snakes were detected across the 33 survey sites in Royal in 1998. Across the four years of survey in Royal NP, Broad-headed Snakes were detected at 33% of sites. Detection rates across reserves where Broad-headed Snakes were detected equate to one snake for every 1.9 hours in 1998 (or 3.2 h overall) in Royal NP, compared to one every 5.0 h in the Blue Mountains NP, one every 5.1 h in Yengo NP and one every 7.9 h in Wollemi NP.

Other reptiles

Another 19 reptile species were detected under loose rocks across all reserves (Table 1). The two most commonly detected species were the Velvet Gecko (486

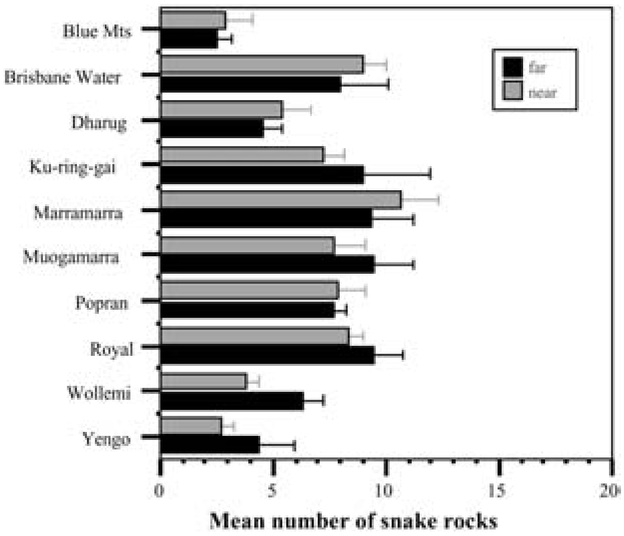

Figure 3. The mean number (± S.E) of rocks available across sites that were considered suitable for use by Broad-headed Snakes.

in total) and the Copper-tailed Skink *Ctenotus taeniolatus* (378 in total). There was a significant difference in the number of Velvet Geckos detected across reserves ($F_{9, 188} = 7.83$, $P = <0.001$), but not across site categories ($F_{1, 188} = .215$, $P = 0.644$). The mean number of Velvet Geckos on transects varied from one to six across both categories (Figure 4). The abundance of Velvet Geckos per 100 snake rocks varied from 7 – 67 (Table 1).

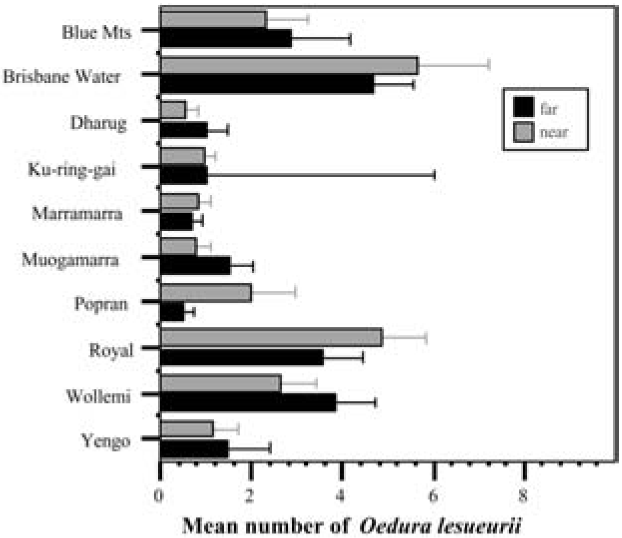

Figure 4. The mean number (± S.E) of Velvet Geckos per transect across ten reserves.

The Thick-tailed Gecko *Underwoodisaurus milii* was located 16 times in five reserves whilst the Stone Gecko *Diplodactylus vittatus* was located ten times in six reserves (Table 1). A further eight species of snake were found to shelter under loose rock. The most commonly detected were the Small-eyed Snake *Rhinoplocephalus nigrescens* with 26 individuals detected across six reserves and the Yellow-faced Whip Snake *Demansia psammophis* with 21 individuals across seven reserves (Table 1).

Habitat disturbance

Habitat disturbance was observed in all of the reserves surveyed (Table 2). Rock cairns and fireplaces were commonly detected and often at a distance (>500 m) from a road or track. These forms of disturbance are attributed to 'hikers'. We observed areas with rock stencils (indicating rock removal) in all but two reserves. This removal did not necessarily mean collection of the rock but more likely deliberate vandalism or destruction, such that the rocks were removed from the platform. In such instances rocks were often found smashed below the rock platform. We also observed habitat disturbance that was consistent with the activities of reptile poachers. Rocks were found to have been dislodged from their original position, leaving a stencil and were often found overturned and in some cases totally removed from the platform (as above). Rocks were also seen to be chipped, broken or smashed; this type of disturbance was seen at sites > 1km from defined tracks. The only locations that appeared to be free of obvious disturbance to loose rock were the remote wilderness areas of Wollemi NP.

Discussion

Distribution of the Broad-headed Snake

The Action Plan for Australian Reptiles identified the need to conduct surveys within the geographic range of the Broad-headed Snake as a fundamental element of devising an effective conservation strategy (Cogger *et al.* 1993). Shine *et al.* (1998) conducted surveys at 18 sites throughout the range of the Broad-headed Snake. We have extended this by conducting surveys at 236 sites across 10 conservation reserves (see Appendix 1 for photos). Both surveys attest to the extreme rarity of this species. We detected Broad-headed Snakes in only four reserves: 1 from 23 sites in Yengo NP, 1 from 24 sites in Wollemi NP, 2 from 22 sites in Blue Mountains NP and 6 from 33 sites in Royal NP (1998 only). Shine *et al.* (1998) detected 11 Broad-headed Snakes from 54.5 hours of search effort (approximately one snake every 6 h), 1 from 4 sites (16 h) in Wollemi NP, 1 from 1 site in Yengo NP (2 h), 1 from 4 sites (8 h) in Blue Mountains NP and 0 from 3 sites (6 h) in Royal NP. We were unable to detect this species from 134 sites in the remaining 6 reserves though there are historic records from three of these. In the event that the Broad-headed Snake was absent or rare historically in these reserves, our surveys still provide important data on the rock habitat and the abundance of the Velvet Gecko.

Our survey data do appear to be indicative of the relative abundance of the Broad-headed Snake across the above four reserves. Our single site surveys in Royal NP in 1998, which were concurrent with surveys in other reserves, detected Broad-headed Snakes at 4 (12%) of 33 sites. This averaged 14% of sites in the subsequent 5-year period (Goldingay and Newell unpublished data). Baker (2003) detected a single Broad-headed Snake in Yengo NP from 30 sites, of which 25 were surveyed twice, confirming the results of our earlier survey. It appears that only at Morton NP in the south of the range does this species reach high abundance, estimated at 33 snakes per km of rock habitat (Webb *et al.* 2002). Shine

Table 2. Disturbance to surface rock across ten reserves near Sydney. Site category is based on distance to road or track (near = <200 m, far >350 m).

	Disturbance Types							
	rock cairns		fire places		rock removal		reptile searching	
Site category	near	far	near	far	near	far	near	far
Marramarra NP	✓	✓	✓	✓	✓		✓	✓
Muogamarra NR	✓	✓	✓	✓	✓		✓	✓
Ku-ring-gai NP	✓	✓	✓	✓	✓		✓	✓
Dharug NP	✓	✓	✓	✓	✓	✓	✓	✓
Popran NP	✓		✓		✓		✓	✓
Brisbane Water NP	✓		✓	✓			✓	✓
Yengo NP	✓	✓	✓	✓	✓	✓	✓	✓
Blue Mt NP	✓	✓	✓	✓	✓	✓	✓	✓
Wollemi NP	✓		✓		✓		✓	
Royal NP	✓	✓	✓	✓	✓		✓	✓

et al. (1998) reported 5 snakes in eight hours of search effort across 4 sites in Morton NP (one snake every 1.6 h) Our estimate for Royal NP is approximately 1 snake per km of rock habitat (Goldingay and Newell unpublished data), and 1 snake every 1.9 hours in 1998. Our annual surveys in Royal suggest that our survey methods were adequate to detect the species in most other reserves.

Our surveys in some reserves may not have been in areas typical of the potential habitat available. Wollemi and the Blue Mountains NPs contain many remote areas. Such areas were not specifically targeted because they were not readily accessible on foot. However, a helicopter was used to access a small number of remote areas in Wollemi NP and a Broad-headed Snake was detected at one of these sites, where there were no obvious signs of habitat disturbance. The importance of wilderness areas for this species has been recognised previously (Perry 1993). Further surveys of remote areas are required to better understand what contribution they may make to the conservation of this species.

One intriguing result of our study was that Velvet Gecko abundance varied significantly across the reserves. This was still the case when standardised for snake-rock abundance, which has a strong influence on gecko abundance (Shine *et al.* 1998). Shine *et al.* (1998) found that snake abundance was positively related to gecko abundance. We only detected Broad-headed Snakes in reserves where gecko abundance was high but our data are too few to test this relationship. There may be other subtle factors operating at the local scale, such as changed vegetation density (e.g. Pringle *et al.* 2003), which influence gecko abundance.

Despite the efforts of this and other studies, many more surveys are needed to better understand the distribution and rarity of the Broad-headed Snake. Such surveys should now only focus on those reserves where recent records have been obtained. The distribution of the species is relatively well known for Morton NP (Webb *et al.* 2002) and Royal NP (Goldingay 1998; Goldingay and Newell unpublished data). Yengo (153,000 ha), Wollemi (493,000 ha) and Blue Mountains NPs (267,000 ha) are each very large and for the most part, have only been surveyed in the easily accessed areas. However, it is unwise to assume that large and apparently remote areas of rock outcrop will offer high quality habitat for this species. The current study found that rocky ridges and outcrops within reserves are often the locations of walking tracks and lookouts, and this will also apply in reserves with declared wilderness areas. Thus, on-ground surveys will be the only way of establishing the true quality of rock habitat and the relative abundance of the Broad-headed Snake.

Disturbance to rock outcrops

Until recently, the literature has been dominated by reports that strongly implicate rock removal for landscaping as the primary cause of habitat degradation for the Broad-headed Snake (Shine and Fitzgerald 1989; Schlesinger and Shine 1994; Webb and Shine 1997b, 2000; Shine *et al.* 1998). Goldingay (1998) first identified that degradation of Broad-headed Snake habitat that is unrelated to bush rock collection, may occur frequently and extensively. Goldingay and Newell (2000) used experimental rock outcrops to confirm this and to demonstrate that its frequency was influenced by proximity to walking tracks or roads within Royal NP. Our surveys in this study confirm that similar patterns of habitat disturbance are evident in most other reserves, though the influence of distance is less clear. Habitat disturbance could be attributed to hikers, reptile poachers and vandals. We did not specifically quantify the different kinds of rock disturbance but each was present in all reserves and was widespread. Constructing fireplaces out of loose rock is illegal, but the widespread occurrence of this practice has contributed to habitat degradation. The construction of rock cairns is another illegal activity that is still practised by some park users. Rock displacement was also evident at sites used by rock climbers in the Blue Mountains NP. Given that these user groups are now commonly entering remote areas, the impacts of their activities may be significant. Unless habitat quality is restored, habitat degradation remains permanent. Similar forms of habitat disturbance have been observed in granite rock outcrops in north-east NSW, indicating that such habitat disturbance is very widespread (Goldingay and Newell in press).

Several authors have cited illegal collection of Broad-headed Snakes as contributing to the decline of this species (Cogger *et al.* 1993). The significance of this has been difficult to recognise. Webb and Shine (1997b) stated that "the conservation problems associated with illegal collecting are likely to be trivial, compared with the problems arising from legal or illegal removal of rocks." Shine *et al*. (1998) stated that "collectors could, at best, find only a small proportion of the snake population at most times of the year." Subsequently, Webb *et al.* (2002) acknowledged the enormous threat that poaching has on this species after collectors repeatedly targeted their study site in Morton NP. They concluded "in the short-term, the greatest threat to this population is the illegal removal of rocks and the collection of snakes". The low reproductive rate and delayed maturation of the Broad-headed Snake (Webb and Shine 1998b) mean that the recovery of a local population from removal of individuals would be slow.

Poaching of Broad-headed Snakes not only removes animals from a population but causes permanent habitat degradation. Collectors often do not reposition rocks dislodged while searching for snakes. Rocks are left upside down and broken (Goldingay and Newell 2000; Webb *et al.* 2002), totally changing their shelter and thermal properties. Large boulders were seen in several reserves that appeared to have been dislodged from platforms with crow-bars. The Broad-headed Snake has been a popular species with reptile collectors in the past (Shine *et al.* 1998) and it appears this has continued due to the number of snake-rocks that were displaced at many locations. Webb *et al.* (2002) reported two major disturbance events associated with poaching of Broad-headed Snakes in Morton NP. Goldingay and Newell (2000; in prep.) observed disturbance from reptile poachers at a number of sites in Royal NP. It is likely that such disturbance occurs more frequently than is currently recognised. Poaching should now be recognised as a highly significant threat to the persistence of populations of this species. Further studies that attempt to assess and mitigate the impact of poaching must be conducted.

There is no doubt that rock removal for landscaping has been a cause of habitat degradation for the Broad-headed Snake (Hersey 1980; Shine and Fitzgerald 1989). Schlesinger and Shine (1994) even presented data on the size distribution of rocks confiscated from rock thieves caught operating within Dharug NP. The absence of rock from some sites that could not be included in this study may have been indicative of historic rock theft. These were mostly from areas close to roads in Dharug and Yengo NPs. It is likely that only the most recent removal would be detected because the only way to know that it has occurred is by the stencil left behind when a rock is removed (see also Shine *et al.* 1998). These stencils may remain distinct for a number of years (<10 years). However, we consider that much of the rock removed at our survey sites has only been displaced locally. This has been observed regularly in Royal NP where some vandals deliberately throw or push rocks off platforms (Goldingay and Newell 2000; in prep.). This has also been documented in Morton NP (Webb *et al.* 2002). Management must focus on mitigating localised rock displacement as the primary cause of on-going habitat degradation.

In the present study, we categorised sites by distance to tracks or roads to use distance as a surrogate for the frequency of habitat disturbance. Our experimental outcrops in Royal NP have demonstrated that disturbance is more destructive and more frequent at near, compared to far sites (Goldingay and Newell 2000, in prep.). However, disturbance to rock outcrops in all of the reserves surveyed was extensive and we frequently encountered high levels of disturbance more than 400m from a track. For example, one extensive outcrop in Ku-ring-gai Chase NP, >1km from a formal walking track, was heavily disturbed by reptile poachers. Virtually all snake rocks showed sign of displacement and many were overturned. A narrow informal track was found that connected the formal walking track to the edge of the outcrop. In several reserves it was difficult to locate far sites due to the positioning of roads and walking tracks, so distance effects may not have been properly tested.

None of the habitat parameters examined showed a response to distance category. This result is similar to that documented previously for Royal NP (Goldingay 1998), and appears contrary to experimental evidence that near sites are disturbed more frequently than far sites (Goldingay and Newell 2000, in prep.). However, the permanence of infrequent disturbance events is likely to have an equivalent impact to that of more frequent disturbance at sites. Thus, the availability of snake rocks becomes equally depleted at all sites. Additional experimental studies are needed to assess whether disturbance frequency is influenced by distance to roads and tracks.

It is likely that there has been a very long history of disturbance within the reserves surveyed. For example, enormous rock cairns that were constructed as survey points ('trigs') along the Hawkesbury River may have been established as early as 1830. These are often located on north through to west facing cliff lines and ridges; areas that are favoured by snakes (Pringle *et al.* 2003). Presumably rocks were removed from surrounding rock platforms to construct them. The purpose of the rock piles was to aid survey and navigation. However, many of these now occur in dense scrub, suggesting that considerable changes in vegetation structure have occurred, possibly due to changes in fire regimes (see Kohen 1996; Pringle *et al.* 2003) or that the areas were cleared initially and not maintained.

Conservation implications

Our surveys have demonstrated two key points. Firstly, the Broad-headed Snake was rare throughout the areas surveyed. We failed to detect it in six reserves immediately north and north-west of Sydney. There are vast areas in these reserves containing apparently suitable habitat as well as the gecko and skink prey of the snake and yet these reserves currently contribute little if anything to the conservation of this species. Where we did detect the snake it was present at very few sites. There is a clear need for further broad surveys through other parts of the geographic range so that any significant populations can be identified. Secondly, habitat degradation is extensive throughout all reserves and appears to be continuing. The intensity of on-going disturbance is demonstrated by recent studies in two reserves (see Goldingay and Newell

2000; Webb *et al.* 2002). These findings should require a reappraisal of the urgency for a recovery plan for this species, and its Commonwealth listing should be upgraded to endangered. The Broad-headed Snake was listed as endangered at the Commonwealth level until the Action Plan for Australian Reptiles (Cogger *et al.* 1993) assigned it to the status of vulnerable.

An intriguing result from this study is the fact that this snake is slightly more abundant in Royal NP, the reserve with the longest history of European visitation in Australia, than the other reserves in which it was found. This reserve may be able to make a substantial contribution to the conservation of the Broad-headed Snake. The effectiveness of various management actions, such as the effectiveness of habitat restoration and policies directed at reducing visitor impacts, and even poaching, could be trialed in this reserve. The extent of on-going habitat disturbance and apparent reptile poaching in many reserves clearly requires a management response. Track closure is an obvious solution (Goldingay 1998; Webb *et al.* 2002). We have conducted small-scale restoration experiments that suggest that the rock habitat of the Broad-headed Snake can be readily restored (e.g. Goldingay and Newell 2000, in prep.). Further research of this kind is required in other parts of the species' range to enhance its recovery.

A corollary of our results is the need to consider the impact of an increase in nature-based tourism because conservation reserves are often the focal point. Tourism has the potential to make a positive contribution to conservation objectives, being able to directly generate revenue for conservation outcomes (Van Oosterzee 2000). Few studies have examined recreational impacts on herpetofauna. Our study suggests that this impact may be substantial in many reserves.

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APPENDIX I

A Broad-headed Snake assuming its threat display after being uncovered from a loose rock.

Photo. R. Goldingay

Close up of the head of a juvenile Broad-headed Snake. The colour pattern on the head is unique and has been used to identify individual snakes in Royal National Park.

Photo. D. Newell

The Stone Gecko was uncommon across the reserves surveyed.

Photo. D. Newell

APPENDIX I

The Lesueur's Velvet Gecko is the primary prey of the Broad-headed Snake.

Photo. D. Newell

The Thick-tailed Gecko is a highly distinctive inhabitant of loose rock habitats.

Photo. D. Newell

Despite extensive areas of suitable habitat along the Hawkesbury River, no Broad-headed Snakes were found.

Photo. D. Newell

Part of a survey transect in Royal National Park.

Photo. R. Goldingay

Ancient rock disturbance in the form of an Aboriginal stone arrangement.

Photo. D. Newell

APPENDIX 1

Part of a survey transect in Royal National Park where people had created a garden of rocks (mid-distance) in which to grow cannabis.

Photo. D. Newell

A suitable snake rock that has been broken and displaced. The bare patch (stencil) on the rock platform is due to the absence of a covering of lichen. This rock disturbance is probably caused by reptile poachers.

Photo. R. Goldingay

Another rock broken by vandals or reptile poachers.

Photo. R. Goldingay

An historic rock cairn in Ku-ring-gai Chase National Park comprised of many rocks suitable for broad-headed snakes. These cairns were constructed as survey points along the Hawkesbury River and may date to 1830.

Photo. D. Newell

APPENDIX I

A rock cairn constructed to aid navigation that is now overgrown suggesting that changes in vegetation structure have occurred.

Photo. D. Newell

A camp fire comprised of bushrock in Royal National Park.

Photo. R. Goldingay

Rocks that have been flipped over exposing the bare rock platform are believed due to reptile poachers. Such disturbance is evident for many years. This disturbance was in Dharug National Park.

Photo. D. Newell